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AUTHOR Karplus, Elizabeth F.; Karplus, Robert
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Abstract

A Piagetian type task, The Island Puzzle, was administered to children grades 5 to 12, tc science teachers attending a Naticnal Science Teachers Asscciatien Convention, and to college physics teachers attending a regional meeting cf the American Asscciatien of Physics Teachers. The procedures differed frcm thcse cf Piaget in that the puzzle was administered to a grcup cf subjects and the individual respcnses were written. Subjects participating in the study were shcwn a map cf four islands and a puzzle involving flights frcm one island tc another was presented alcng with clues. Three questicns were asked abcut whether flights cculd be made between certain islands. Answers tc the questicns were grouped into six different categories. A tctal of 449 subjects were involved in the study. Results cf the study indicate that intellectual development in abstract reascning progresses gradually frcm grade 5 tc grades 10 tc 12, where little further progress is made and abstract reasoning reaches a plateau. The sequence cf six categories established in this study appear to be very clcse to the sequence Piaget and his ccllaboratcrs have fcund applicable to the tasks investigated by them. (BB)

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INTELLECTUAL DEVELOPMENT BEYOND ELEMENTARY SCHOOL

by

Elizabeth F. Karplus and Robert Karplus

Science Curriculum Improvement Study
Lawrence Hall of Science
University of California, Berkeley

The Islands Puzzle (Figure 1) was created as a tool to assess abstract reasoning ability. The "clues" given as part of the puzzle must be analyzed and used to draw certain conclusions, as explained in Figure 1. Note that both an answer and an explanation of the answer in terms of the clues are required. In this way our study is similar to those of Piaget.[1] Furthermore, we have found it most useful to examine and categorize the explanations, just as is done by Piaget. Our procedure deviates from that of Piaget, however, in that the puzzle is administered to a group of subjects and that the individual responses are written. It is therefore not possible to investigate a particular subject's thinking beyond the level of the standard questions. Furthermore, we have not conducted any longitudinal studies in which the development of a single individual is observed over several years.

Because the answers are written, the puzzle has been presented only to fifth graders and older persons. Phillips,[2] who has recently reported on a classroom presentation of Piaget-type tasks, was able to work with fourth, fifth, and sixth graders and found considerable agreement between individual and group responses.

Method of Presentation

For all groups studied, the task was administered by the authors or a specially trained assistant. The subjects were shown a map of the four islands (Figure 1), which we designated by the indicated names for the children, by letters for the high school students and adults. Then the introduction was presented; it was emphasized that all plane routes operated in both directions, and that non-stop trips or trips with stops or plane-changes were equivalent. No "practice questions" or other teaching was provided. The results of a pilot study where practice was provided are reported in an Appendix to this paper.

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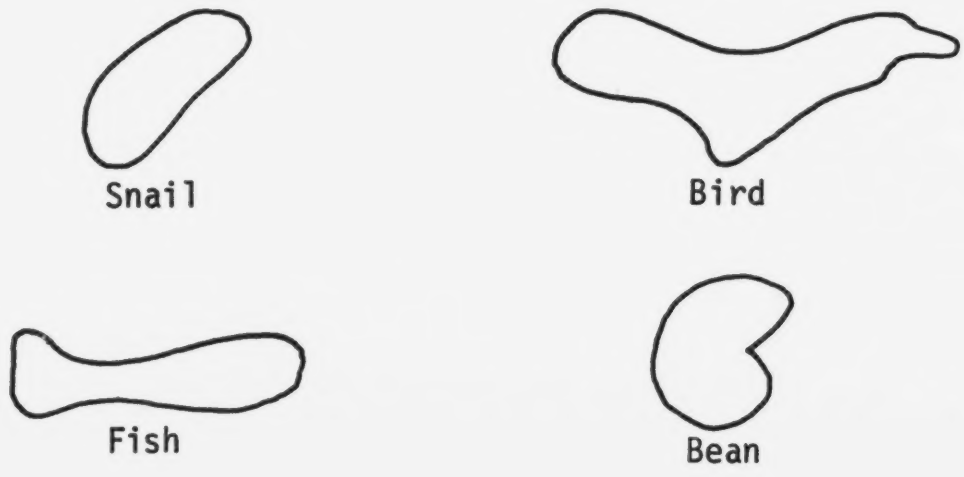
Figure 1. Islands Puzzle



Introduction: The puzzle is about four islands in the ocean. People have been traveling among these islands by boat for many years, but recently an airline started in business. Listen carefully to the clues I give you about possible plane trips. The trips may be direct or they may include stops on one of the islands. When I say a trip is possible, it can be made in both directions between the islands.

This is a map with the four islands, called Bean Island, Bird Island, Fish Island, and Snail Island. You may make notes or marks on your map to help you remember the clues. Raise your hand if you have questions about the clues.

First clue: People can go by plane between Bean and Fish Islands.

Second clue: People cannot go by plane between Bird and Snail Islands.

Use these two clues to answer question 1.

Question 1: Can people go by plane between Bean and Bird Islands?
Yes?___ No?___ Can't tell from the two clues.___
Explain your answer.

Third clue: People can go by plane between Bean and Bird Islands.

Use all three clues to answer questions 2 and 3. Don't change your answer to question 1.

Question 2: Can people go by plane between Fish and Bird Islands?
Yes?___ No?___ Can't tell from the three clues.___
Explain your answer.

Question 3: Can people go by plane between Fish and Snail Islands?
Yes?___ No?___ Can't tell from the three clues.___
Explain your answer.

Most of the groups had answer sheets with the map and the three question items, but the introduction and clues were always presented orally and clarified with the aid of a blackboard map. The clues were repeated as often as requested by the subjects. Nevertheless, it was clear from a few of the answers that some subjects were confused by the clues and did not remember the details correctly. The completion of the puzzle required between ten and fifteen minutes.

At this point the reader may wish to attack the Islands Puzzle and record his answers and explanations on a piece of paper.

Categorization of Responses

One subjective aspect of this study is our categorization of a subject's explanation of his answers. As we have pointed out, the fact that the task was presented to groups prevented detailed exploration of the reasoning of individuals. Some of the responses are very brief and therefore ambiguous; these may represent inadequate reasoning or the subject's judgment that the answer is so obvious it could be explained briefly. Nevertheless, we have established a sequence of six categories which comes very close to the sequence Piaget and his collaborators have found applicable to the tasks investigated by them.[2] A description of the categories follows.

Category N: no explanation or statement "I can't explain."

Category I (pre-logical): an explanation which makes no reference to the clues and/or introduces new information. Subcategories are the mere repetition of the answer to be explained (to #2, "Yes, because there are flights"), appeal to the diagram itself (to #2, "No, because it is the diagonal" or to #3, "Yes, because it is close"), and fanciful stories (to #1, "No, because there is a strong air pocket that no one can survive" or to #2, "No, because the plane can run out of gas and go down in the water").

Category IIa (transition to concrete models): direct appeal to or repetition of clues (#1, "No, because you did not say so" or to #1, "Can't tell because you didn't say"). Since all three questions require inferences, a direct appeal to the clues does not provide a logical justification.

Category IIb (concrete models): the clues are used to construct models which are then used to make the predictions. The most common model provides for the presence or absence of airport facilities on an island, according to whether flights were or were not said to reach it (to #1, "Can't tell, because Bean Island has an airport, but Bird Island might or might not have an airport"; to #2, "Yes, because there must be an airport on Bird Island, so the people from Fish Island can get there"; to #3, "No, Snail must

be the one with no airport, so people from Fish Island can't get there"). This model-based approach, when correctly used, leads to correct answers to all three questions in the problem. It assumes information not given in the clues, however, and cannot be generalized to solve similar puzzles with different data.

Category IIIa (transition to abstract logic): logical explanation to question 2, that Bird Island can certainly be reached from Fish Island by way of a stop at Bean Island (to #2, "Yes, Fish to Bean to Bird"). Since the logical inference from the two positive statements (clues 1 and 3) needed for question 2 is easier, in our view, than the use of the negative statement (clue 2), question 2 does not make maximum demand on the subject's reasoning ability. We have therefore classified the logical answer here as being transitional to the abstract stage, rather than representing attainment of the abstract stage.

Category IIIb (abstract logic): logical explanations to questions 1 and 3 (to #1, "Can't tell because there is no information linking either Bean or Fish Island with Bird Island"; to #3, "No, because a flight between Fish and Snail would make possible a route between Bird and Snail via Bean and Fish; this contradicts the second clue").

It is clear that these six categories must be viewed as tentative pending further study, in depth, of the reasoning of individual children and adults. The only difficulty we encountered was with a large number of explanations of the form "inadequate information" to question 1. The response rarely included a comment as to how or why the information was inadequate. We did not know whether the subject actually knew the logical reason, or did not and drew the conclusions on partially intuitive grounds. We therefore interpreted these answers in the light of the explanations offered to questions 2 and 3.

The descriptive terms "pre-logical," "concrete models," and "abstract logic" are used here to refer to sub-stages in the transition from concrete to formal thought, since our observations make this refinement necessary. Furthermore, we believe we have found here indications of a development that is analogous to the pre-operational--concrete operations--formal operations sequence,[1] in which reference to concrete models takes the place of actions on concrete objects.

Results

A total of 449 subjects in six distinct groups participated in this investigation (Table 1). The groups range from fifth and sixth graders to NSTA members at the 1969 convention and college physics teachers at a regional meeting of the American Association of Physics Teachers. The percentage of subjects in each group placed in each

category of explanation is reported in Table 2. For the purposes of this table, a subject was placed in the category of his explanations if all three fell within the same category. If they varied, and this was usually the case, an intermediate category was chosen. Thus, a logical answer to #2 (IIIa) and a repetition of clues to #3 (IIa) resulted in the assignment of the subject to category IIb.

Table 1. The Subjects

Subject Group	Number	Designation of Group
Suburban fifth and sixth graders	55	"5-6"
Suburban seventh, eighth, and ninth graders enrolled in a science class	78	"7-9"
Suburban tenth, eleventh, and twelfth graders in several college preparatory classes	98	"10-12"
Suburban twelfth graders in physics classes	66	"12P"
NSTA Convention participants at Piaget symposium	83	"NSTA"
American Association of Physics Teachers	69	"AAPT"
Total subjects	449	

It can be seen in the table that there is a gradual progress of the group median from category I for the "5-6" group to category IIa for the "7-9" group and finally category IIb for the "10-12" group. Curiously enough, there is little further progress even on the part of the adult groups. Perhaps a psychological set created by the introduction is limiting the logical thought.

Table 2. Evaluation of Explanations (percent)

	Group					
Category	"5-6"	"7-9"	"10-12"	"12P"	"NSTA"	"AAPT"
N	24	3	1	9	10	0
I	40	39	9	15	4	3
IIa	11	26	13	6	18	6
IIb	18	18	62	47	54	51
IIIa	7	15	11	15	8	27
IIIb	0	0	3	8	6	13

More specifically, a large fraction of no explanations (N) by the "5-6" group disappears for the later groups. This is not surprising. Conversely, answers placed in the category of abstract thought (IIIb) are completely absent from the tested samples of fifth to ninth graders and appear only with high school groups. Since the abstract explanation is quite complicated to write down, it is likely that some of the younger children would display a better performance in an interview compared to a written examination. The combined levels IIIa and IIIb show surprisingly little variation from group to group, with the "5-6" being somewhat lower than the average and the high school physics group being somewhat higher but both at the borderline of statistical significance. Only the college physics teachers show a significantly increased percentage in the categories IIIa and IIIb.

A few interesting results are not revealed by Table 2. The high school groups, for instance, include about 30% model makers (within the scope of category IIb), while the "NSTA" group has less than 10% model makers. Almost all the adults answer logically (IIIa) to #2 but very many appeal to the clues directly (IIa) to items #1 and #3. Perhaps the cognitive style, rather than only the intellectual level of a subject, influences his response. Also, various groups use different techniques for record keeping. Diagrams are used by some, complete statements by others, abbreviated notes by most adults.

Because the total number of correct answers (that is, the answer pattern "Can't tell"--"yes"--"no"--which makes optimal use of the information given) is quite small--only 78 out of 449 subjects--and because the percentage varies only slightly from group to group (from 9% in the "5-6" group to 25% in the "AAPT" group), we have combined the five groups into one and the six categories into three. The numbers and percentages of subjects giving correct answers are reported in Table 3. As might be expected, subjects who explain their answers on a higher level of abstraction are much more successful in obtaining correct answers than the others. From zero correct answers in the N, I category the percentage rises to 60 in category III. On a random basis, one would expect about 3% correct answers (1 in 27) since there are three questions with three options each. Even the level II subjects perform somewhat better than random, but the excess is only at the borderline of statistical significance.

Table 3. Correct Answer Patterns

Category	Number of subjects	Number of correct answers	Percentage of correct answers
N, I	106	0	0
IIa, IIb	254	25	10
IIIa, IIIb	89	53	60
Total	449	78	

Discussion

It is clear from this study that intellectual development in abstract reasoning, as defined by the "Islands Puzzle," reached a plateau in the high school age group and did not progress much further. In addition, the plateau is at a disappointingly low level.

The following question of educational policy is thereby raised: is it a desirable educational objective that a larger fraction of the adult population (other than college physics teachers) should be able to answer the Islands Puzzle or an equivalent task on the level of abstract thought? We are pleased to be able to state this objective in such clear-cut behavioral terms, and we solicit the reader's opinion on the matter. If the answer is "yes," then the problem becomes one of designing a suitable educational program. Unfortunately, even the behavioral statement of the objective does not tell us how to proceed, and we again solicit the reader's suggestions.

Even though one can conceive other and better ways of posing the logical task than through the Islands Puzzle, we believe that this preliminary study calls attention to a neglected area of educational research which has significant bearing on large-scale improvements in scientific literacy. It is furthermore likely that tasks can be constructed to assess conservation reasoning, combinatorial logic, mathematical proportion, and other components of formal thought. What will these reveal about the intellectual level of our high school and adult populations?

We are indebted to Beverly R. Karplus and Margaret A. Karplus for assistance in the study. It was supported in part by a grant from the National Science Foundation.

References

1. B. Inhelder and J. Piaget. The Growth of Logical Thinking from Childhood to Adolescence. Basic Books, New York, 1958.

2. Darrell G. Phillips. Individual Interview versus Classroom Group Presentation of Piaget-type Tasks. NSTA, Dallas, Texas, March, 1969.

Appendix

It is well known that even a brief teaching or "practice" exercise improves performance on many tests. Presumably the practice furnishes a pattern for the subject's subsequent performance. Even though more of the subject's ability is thereby brought to bear on the test, there is a question of just how applicable this ability is to situations where the subject is not cued by a practice item. We therefore consider it an open question as to whether a performance on the Islands Puzzle with or without a practice item is a more satisfactory indicator of intellectual development. Nevertheless, we have investigated the effect of a brief "practice" activity to explore this alternative.

The nature of the Islands Puzzle is such that many different forms of "practice" could improve performance. Since we were only concerned with identifying an effect, we chose to have the task administrator pose and answer a question analogous to puzzle question 3, which was the most difficult one for the subjects. The following statement was inserted after the introductory paragraph (Figure 1) and before the answer sheets with the pictured islands were distributed:

"I'll now give you one puzzle as an example, and I'll tell you my answer to this puzzle. Then, I'll give you another puzzle and a piece of paper on which you can write your answers.

"In my puzzle there are three islands, Island X, Island Y, and Island Z. (Three islands are drawn in a triangular arrangement on the chalkboard. During the subsequent explanation, the islands mentioned are indicated by hand gestures.) Now I'll give you two clues. The first clue is that people can go by plane between Islands X and Y. They can go in both directions, and it may be direct or with a stopover. The second clue is that people cannot go by plane between Islands X and Z. They cannot go from X to Z or Z to X either directly or by stopping somewhere.

"There is only one question left; what about plane trips between Islands Y and Z? Can people go by plane between Islands Y and Z? You could answer 'Yes' or 'No' or 'Can't tell from just the two clues!' Now I'll tell you my answer, and then I'll explain the reason for my answer by using the two clues.

"My answer is 'No.' And the explanation goes like this: according to the first clue, people can go by plane from X to Y. Now, if there are planes to go from Y to Z, then people can go from X to Y and catch another plane from Y to Z. That way they could get from X to Z. But this contradicts the second clue, which said that people could <u>not</u> go by plane between X and Z. Therefore, people cannot go by plane between Y and Z."

Three groups of students, each in the same school as the corresponding group identified in Table 1, worked on the Islands Puzzle after the practice exercise. The results of their work are presented in Table 4 and may be compared with those for the first three groups in Table 2.

Table 4. Evaluation of Explanations with Practice (percent)

Category	Group "5-6" (N = 44)	"7-9" (N = 139)	"10-12" (N = 114)
N	5	2	2
I	20	10	11
IIa	30	24	16
IIb	45	45	33
IIIa	0	13	24
IIIb	0	6	15

It is clear that all three groups show substantial gains. The number of students in category I has decreased dramatically. The median has shifted upward for each group, to category IIa for the "5-6" group, to category IIb for the "7-9" group, and above category IIb for the "10-12" group. The single most noticeable change in the individual answers is the appearance of hypothetico-deductive statements (to #1, "Yes, if Bean can go to Fish, then I think it could go to Bird ") even though the logic of these statements is frequently incorrect. Still, the steady advance with grade level from pre-logical to abstract logical thinking is very similar to the advance in the puzzle without practice. As might be expected, the number of students with a correct answer pattern has increased (Table 5, compare with Table 3), but is still far from complete.

Table 5. Correct Answer Patterns with Practice

Category	Number of subjects	Number of correct answers	Percentage of correct answers
N, I	42	2	5
IIa, IIb	185	55	30
IIIa, IIIb	70	51	79
Total	297	108	

One last point should be made. The students reacted to the practice puzzle with subdued but noticeable signs of dismay. This had not been the case at all when no practice was provided.